Urban Area Microzonation as Prevention in Managing Earthquake Risk

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Abstract

Earthquake risk management represents a preventive measure the protection against earthquakes. To manage earthquake risk, it is necessary to perform seismic microzoning of urban areas threatened by catastrophic earthquakes, i.e. create hazard maps of distribution of peak ground acceleration upon the free surface, fundamental periods in elastic and plastic range of vibration of the soil deposit, and spectral amplitudes upon the free surface. For their elaboration, it is necessary to compute the uniform hazard at bedrock and the dynamic response of the soil deposit in the terrain of the urban city area. The uniform hazard is established for different probability definitions of seismic action as recommended by national or international regulations for seismic design according to types of structures.

Presented as an example in this paper is the seismic microzoning of the urban area of the Skopje city (UPS) for the seismic action with a probability of exceedence of 10% for a time period of 50 years (annual probability of exceedence of 0.0021, or a referent return period of 475 years).

Keywords

Seismic Zoning; Seismic Hazard; Amplification; Fundamental Period

Introduction

Protection of human lives and material goods imposes continuous amendment and upgrading of knowledge according to scientific and research achievements and its incorporation in the regulations for construction of seismically resistant structures. However, scientific knowledge can also be used as a preventive measure to achieve better protection of human lives and material goods at a lower cost. For that purpose, it is necessary to use scientific knowledge as a basis for urban planning and apply it in the process of design and meeting the requirements prescribed by the regulations for seismic construction.

The soil deposit exerts an influence by amplitude-frequency modification of the arrived seismic effect at bedrock, i.e. by amplification or de-amplification of amplitudes of parameters of motion at bedrock and simultaneous modification of the frequency of vibration of the soil deposit during the transfer of the seismic effect (Stamatovska., 2010). Definition of the amplitude-frequency modification of the seismic effect is important for urban planning from the aspect of seismic risk management. Knowing the distribution of fundamental periods in the elastic and plastic range of vibration of the soil deposit, urban planning is performed by avoiding the conditions of resonance of the structure placed at a certain location. Also, with the distribution of the spectral amplitudes upon the free surface, it is possible to provide, through selection of the dynamic characteristics of the structure, a greater seismic safety at a lower cost. In addition to this, seismic microzoning enables physical planning of different types of structures, depending on their importance and purpose in emergency conditions. These benefits of seismic microzoning represent useful preventive measures of protection against earthquakes which is the purpose of many investigations.

For the microzoning of urban areas, definition of the amplification factor and the predominant frequency/or period of the soil deposit is of a particular importance. One of the frequently used methods is based on the H/V spectral ratio (Hakimura et al., 1983, Hakimura, 2008) developed by application of strong motion records in the beginning and later, by application of microtremors and comparison between the two types of investigations.

The method applied in these investigations is different from those that have so far been applied by use of the H/V spectral ratio since it is based on definition of the amplification factor and the predominant period

during the seismic effect, using the dynamic response of representative soil models, whose number of layers is defined by use of microtremor records for the Skopje city.

Seismic Microzoning

The documentation necessary to perform seismic microzoning of urban areas includes:

- Hazard maps of distribution of PGA at the free surface of the terrain;
- Fundamental periods of vibration of the soil deposits prior to (elastic period- T^{el}) and during the earthquake effects (plastic periods - T_i^{pl}),
- Spectral amplitudes at the free surface of the terrain as spectral acceleration (SA), spectral velocity (SV), spectral displacement (SD) and Fourier amplitude spectrum (FS);

To elaborate the documentation for the seismic microzoning of urban areas, it is necessary to compute:

- the uniform hazard of the parameters of motion at the bedrock/or engineering bedrock, and,
- the dynamic response of the soil deposit lying on bedrock.

The documentation used as a basis for seismic microzoning of the UPS has been elaborated according to the "tomographic net" concept.

"Tomographic net" concept

For the urban area of Skopje city, a 3D "tomographic net" (net of main structural cells of the geospace of the UPS with equal dimensions) has been established (Mirakovski et al., 2011). Accepted as a main tome is a square cell with side of 1 km (area of 1 km²), in horizontal plane of UPS. By dividing the main tomes into 4 equal tomes, the tomographic net of the UPS has been established with squares with a side of 500 m. The thickness and the number of tomes in the vertical plane depend on the lithophysical structure of the geospace of the UPS. The representative litho-physical parameters are referenced for the center of the tomes (Fig. 1).

Uniform seismic hazard at the bedrock

The uniform hazard at bedrock depends on the seismotectonic characteristics of the terrain in the

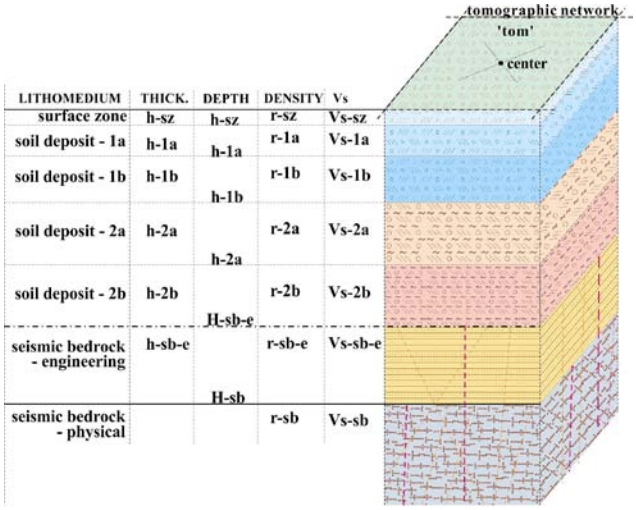
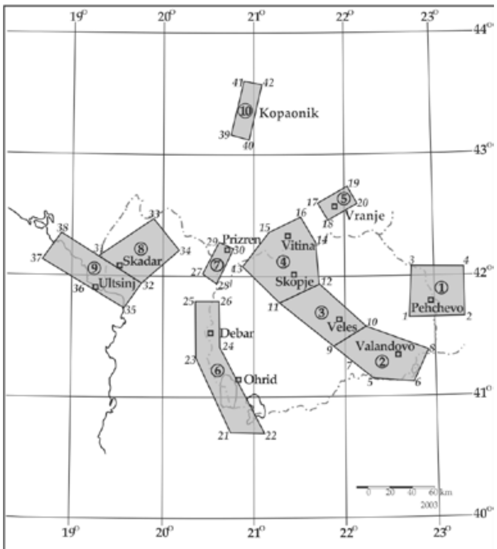


FIG. 1 1D SEISMOGEOLOGICAL MODEL OF ONE 'TOM'

urban area and its wider surroundings (Shebalin et al., 1974; Jordanovski et al., 1998; Arsovski& Hadzievski., 1990; Arsovski., 1997). The uniform hazard at bedrock is defined by application of the PSHA method, developed by Cornell., 1968, and application of EQRISK computer programme (Mc Guire., 1978).



SEISMIC SOURCES

	Maximum magnitude $M_L max$		Maximum magnitude $M_L max$
① Pehchevo	7.9	⑦ Prizren	6.2
② Valandovo	6.9	⑧ Skadar	7.0
③ Veles	6.0	⑨ Ulcinj	7.4
④ Skopje-Vitina	6.5	⑩ Kopaonik	6.4
⑤ Vranje	6.2	Background	5.7
⑥ Debar-Ohrid	6.9		

1, 2, 3, ... , Coordinates of the seismic sources

FIG. 2 SEISMIC SOURCES MODEL

The PSHA includes: mathematical modeling of seismic sources, recurrence relationships for seismic activity of each seismic source and ground motion models. Seismic sources have been defined in respect to their spatial position, size, shape and maximum expected

magnitude through mathematical modeling. Ten seismic sources have been defined (Fig. 2).

On the basis of available catalogues (1901-2002 $M_L \geq 4.5$) the recurrence relationships have been defined according to the maximum likelihood method (Weichert et al., 1980; Bernice., 1985). The recurrence relationships for seismic sources Skopje-Vitina and Pehchevo are shown in Figs. 3 and 4.

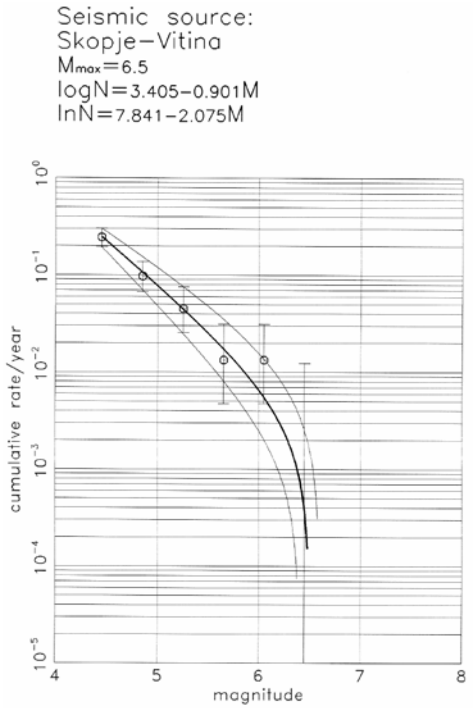


FIG. 3 RECURRENCE RELATIONCHIP FOR SKOPJE-VITINA SEISMIC SOURCE

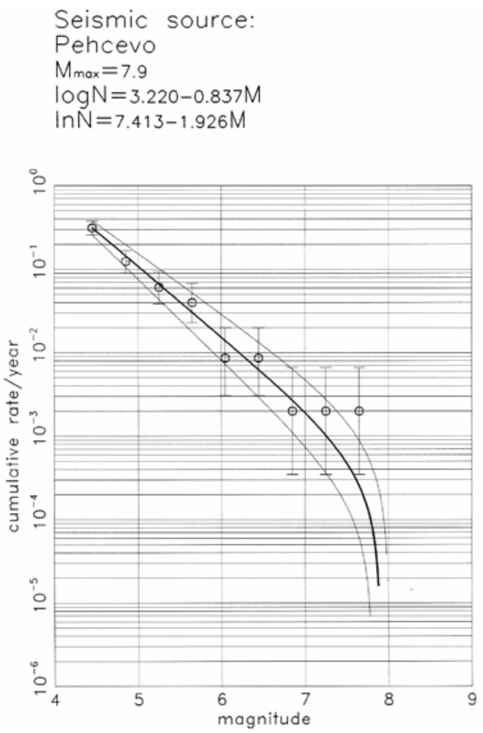


FIG. 4 RECURRENCE RELATIONCHIP FOR PEHCHEVO SEISMIC SOURCE

Four ground motion models: (Ambraseys et al., 1996; Sabetta&Pugliese, 1996; Naumovski, 1984, and Stamatovska et al., 1994, 2006) have been used as alternative and equally probable, and refer to the type of soil with a velocity of shear waves of $V_S \geq 700 m/s$.

The uniform hazard at bedrock of UPS has been computed for SA for 5% of the critical damping and 8 models of a single degree of freedom system with periods between 0.05 and 2.0 seconds (T = 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 1.0 and 2.0), and for five types of seismic action. These are the seismic action with a 10% probability of being exceeded in 10 years, and the seismic action with a 50%, 10%, 5% and 2% probability of being exceeded in 50 years, or referent return time periods of 95, 145, 475, 975 and 2475 years, respectively. These seismic actions are referent according to the regulations of Eurocode 8 and UBC-97, as well as the recommendations of the International Commission on Large Dams–ICOLD (Bulletin No.72-Selecting Seismic Parameters for Large Dams – Guidelines).

The results of the seismic hazard analyses are presented graphically in Figure 5. Each curve represents the mean uniform hazard elastic spectrum of acceleration – SA for 5% damping and horizontal direction and refers to one type of seismic action. Each of its amplitudes is defined by an equal probability of being exceeded for the corresponding referent return period. The seismic action with the least probability of exceedence has the largest amplitudes and vice versa. The value of SA for a period close to zero represents the PGA. It amounts to 0.129g, 0.148g, 0.211g, 0.256g and 0.330g, respectively.

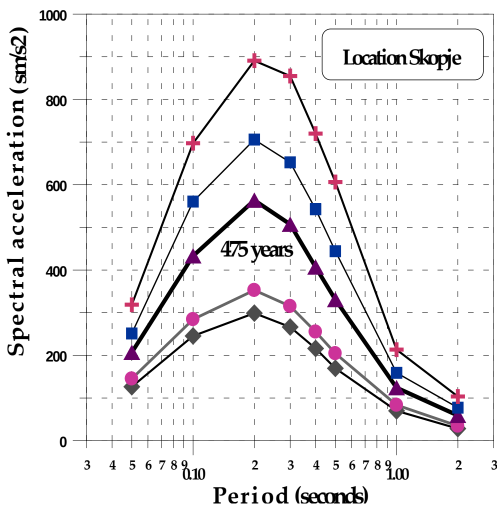


FIG. 5 MEAN UNIFORM HAZARD ELASTIC SPECTRA AT BEDROCK, FOR HORIZONTAL DIRECTION AND 5% DAMPING OF CRITICAL

For dynamic analysis of the models of the soil deposit, each hazard curve is presented by a time history of acceleration that is consistent with the hazard curve used as a "target spectrum".

Dynamic Response of Soil Deposit

Based on data from geological, geomechanical and geophysical investigations of the Skopje city area that have so far been performed for different purposes and in different time periods, the representative soil models have been defined. To define their geological and lithological composition and thickness of quaternary deposits, there have been used data from engineering geological, hydrogeological, geophysical and microtremor investigations performed for the wider UPS area for the needs of its microzoning and reconstruction after the catastrophic earthquake of 26 July 1963 (Gojic and Arsovski, 1963-1964; Arsovski et al., 1964) as well as all the other investigations that have been performed since 1963 (Aleksovski et al., 1990).

Dynamic analysis of the representative soil models of UPS has been done by application of the SHAKE2000 software. In the analytical procedure of using the SHAKE2000 program, the following assumptions are included: the soil system stretches infinitely into a horizontal direction; each layer of the system is homogeneous and isotropic, defined by shear modulus-G, critical damping coefficient-D, density-ρ and thickness-h; the system's response is induced by vertical propagation of the shear waves; shear waves are assigned by the time history of acceleration assigned by a defined number of points at equal time intervals; the dependence of the shear modulus and damping upon shear strains is included in the analysis by the equivalent linear method.

For analysis trough use of the SHAKE2000 software, the soil models have been defined as a "soil column" composed of layers characterized by bulk density γ, seismic V_P and V_S velocities and thickness- h of layers. The equivalent linear soil characteristics for sand, clay and stone rocks have been taken according to the relationships defined by Seed-Idriss, 1972, (Figs. 6 and 7) and incorporated in the Darandeli, M.V. 2001 model in SHAKE 2000 software.

63 representative soil models have been selected for 1D analysis. The composition of 22 models is predominantly represented by gravel and sand, 27 are mainly made from clay and dust, and the remaining 14 models represent a mixture of clay, sand, gravel and dust. 1D dynamic analysis has been performed and the dynamic response parameters have been computed for each model. Parameters of dynamic response are the elastic spectra of acceleration at the free surface of the terrain, for a horizontal direction and for 5% of the critical damping, and the plastic period of vibration.

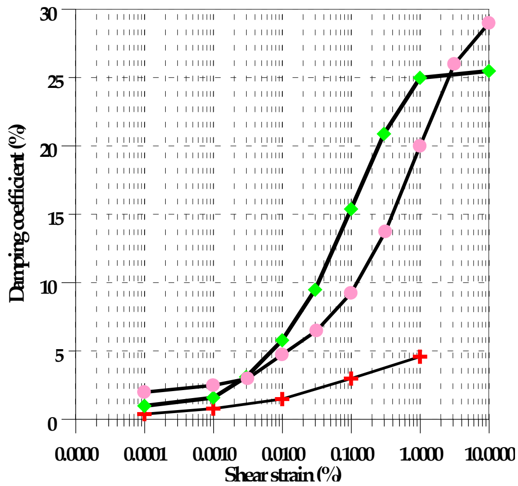


FIG. 6 DAMPING COEFFICIENT- SHEAR STRAIN RELATIONSHIP

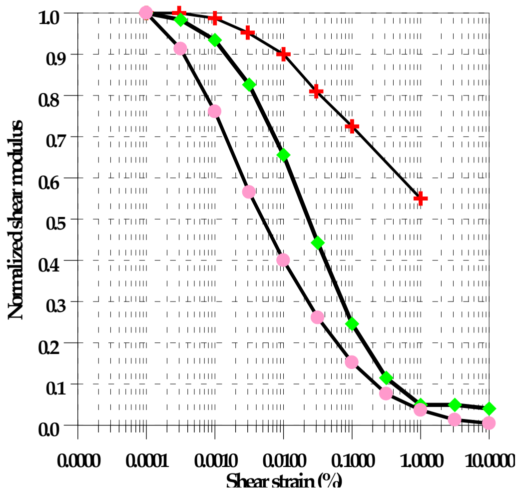


FIG. 6 NORMALIZED SHEAR MODULUS- SHEAR STRAIN RELATIONSHIP

1) Local Amplification and Deamplification

To define hazard maps for SA of UPS, empirical functional relationships for the dynamic amplification factor-DAF have first been established as a variable depending on the characteristics of the deposit: average value of shear velocity - $\overline{V_s}$ and total thickness of the „soil column" - H, as independent variables. $DAF(T_i)$ is the ratio between the spectral acceleration at the free surface - $SA(T_i)^{Ff}$ and the spectral acceleration at bedrock - $SA(T_i)^{B}$, for period T_i. When greater than a

unity, its value points to amplification of the spectral acceleration upon the surface of the deposit and vice versa, deamplification, if less than a unity. The empirical functional relationship for $DAF(T_i)$ for a referent return period has been defined by the following equation:

$$DAF(T_i) = \frac{SA(T_i)^{Ff}}{SA(T_i)^{B}} = \exp(a_1)H^{a_2}(\overline{V_s})^{a_3}\exp(\sigma_{DAF(T_i)})$$

where: a_1, a_2, a_3 are regresion coefficients, while a $\sigma_{DAF(T_i)}$ is the standard deviation. These have been defined by using the multi-linear regression analysis method, while their values for three types of material, for period $T \approx 0$ s, or PGA, are given in Table 1.

TABLE 1 REGRESION COEFFICIENTS AND STANDARD DEVIATIONS FOR DAF(PGA)475

Type of materials	Regression coefficients			Standard deviation
	a_1	a_2	a_3	$\sigma_{DAF(PGA)475}$
Sand-gravel	-11.58736	-0.85845	2.44551	0.11159
Clay-dust	1.93883	-0.32169	-0.06277	0.15829
Mixure	-11.35855	-0.74425	2.31027	0.12087

The obtained values of the regression coefficient a_2 show that DAF(PGA)475 is inversely proportional to H for all three types of material, whereas the values of a_3 show that it is proportional to $\overline{V_s}$ for sand-gravel and mixture, which is not the case with clay-dust. The value of the standard deviation as natural logarithm is 0.112, 0.158 and 0.121 or, to compute median + one standard deviation of DAF(PGA)475, it is necessary to multiply the values of the median by 1.118, 1.172 and 1.128, for sand-gravel, clay-dust and mixture, respectively.

The obtained empirical functional relationships for DAF(PGA)475 are graphically presented in figures 8, 9 and 10 as a median. In these figures, the ordinate axis presets $\overline{V_s}$ (m/s), while the abscissa axis shows H in m. Fig. 8 refers to sand-gravel, Fig. 9 refers to clay-dust, while Fig. 10 refers to a mixture of material. Fig. 8 shows that DAF(PGA)475 has a value that is less or greater than 1.0 which proves that the deposit composed of sand-gravel also amplifies and deamplifies. A thin deposit with small values of $\overline{V_s}$ can reach up to 3 times greater value of acceleration upon the surface of the deposit, while the deep deposit deamplifies, which leads even to neutralization of the seismic effect at the seismic base. Clay-dust soil deposit, Fig. 9 is characterized by DAF(PGA)475 greater than 1. A thin deposit with low values of $\overline{V_s}$, reaches amplification greater than 3. Unlike sand-gravel, clay-dust performs very slight deamplification for a limited range of values $\overline{V_s}$ and H. In the case of a mixed deposit (Fig. 10), deamplification depends on the domination of either sand-gravel or clay-dust and is considerably lower than the deamplifcation in the case of sand-gravel.

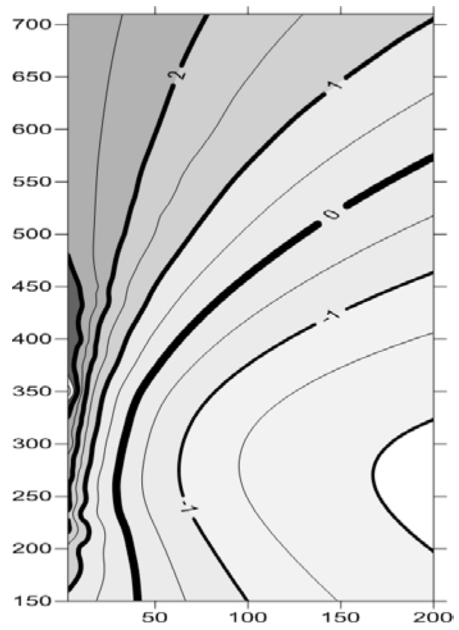


FIG. 8 DISTRIBUTION OF DAF(PGA)475 FOR SEND-GRAVEL

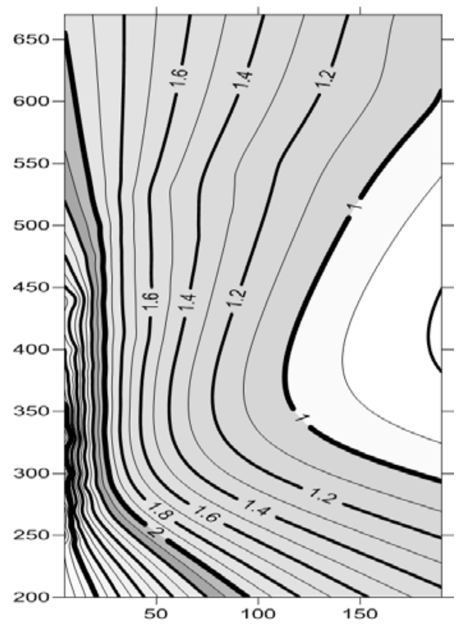


FIG. 9 DISTRIBUTION OF DAF(PGA)475 FOR CLAY-DUST

2) Period of Vibration of Soil Deposit

The fundamental period of vibration of the soil deposit is an important parameter of behaviour of the soil deposit during the seismic effect. For a referent return period, it is a function of the average velocity- $\overline{V_s}$ and total thickness of the soil deposit- H. The fundamental vibration period of the soil deposit before earthquake effect (elastic period- T^{el}) and during the earthquake effect is changed and, in addition to the mentioned

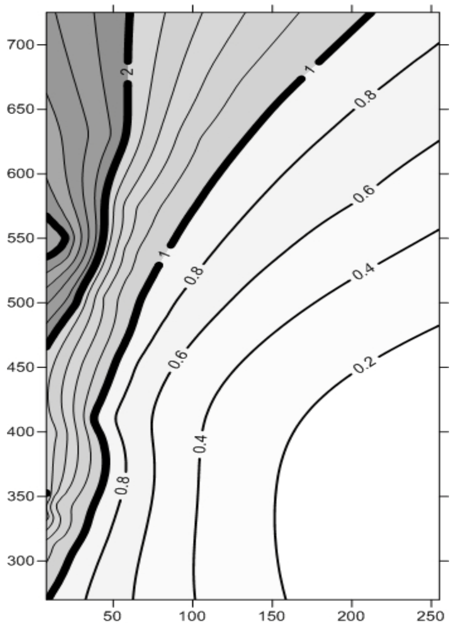


FIG. 10 DISTRIBUTION OF DAF(PGA)475 FOR MIXTURE

parameters, it also depends on the size of acceleration at bedrock defined trough a uniform hazard. In fact, during the earthquake effect, the elastic fundamental period turns into plastic (T_i^{pl}) and its value is increased, i.e. it is displaced in the range of higher periods.

Due to the modification of the fundamental period of vibration of the soil deposit during an earthquake effect, it is possible that it concurs with the fundamental period of the structure and that the structure vibrates in the range of resonance. Therefore, knowledge of the fundamental periods of vibration for different types of seismic actions, recommended by the regulations, is an important preventive measure of seismic protection and hence for seismic risk management.

Also, for the fundamental period of vibration of the soil deposit in the plastic range- T_i^{pl} , there have been computed the functional relationships for all types of materials and each type of seismic action. The functional relationship for the seismic action with a referent return period of 475 years is given by the following equation:

$$T_{475}^{pl} = T^{el}\exp(a_1)\cdot H^{a2}(\overline{V_s})^{a3}\exp(\sigma_{T_{475}^{pl}})$$

Table 2 contains regression coefficients and standard deviations obtained by application of the multi-linear regression analysis method. Regression coefficient a_2 has both positive and negative values, which shows that T_{475}^{pl} is in proportion to H for clay dust, while it is inversely proportional to H for sand-gravel and mixture. The regression coefficient shows that T_{475}^{pl} is in proportion to $\overline{V_s}$ for sand-gravel and is inversely proportional to clay-dust and mixture. The computed values of standard deviation show that the empirical model applied for T_{475}^{pl} provides good fitting with the data so that its value as a natural logarithm is very low, amounting to 0.04, 0.06 and 0.03 for sand-gravel, clay-dust and mixture, respectively. This, on the other hand, means that there will be no important difference between the distributions of T_{475}^{pl} as median and median + one standard deviation of UPS.

TABLE 2 REGRESION COEFFICIENTS AND STANDARD DEVIATIONS FOR T_{475}^{pl}

Type of materials	Regression coefficients			Standard deviation
	a_1	a_2	a_3	$\sigma_{T_{475}^{pl}}$
Sand-gravel	-1.05771	-0.06145	0.25555	0.03899
Clay-dust	2.71842	0.01201	-0.33148	0.06009
Mixture	4.26847	-0.01997	-0.56198	0.03056

Figs 11, 12 and 13, graphically show the empirical functional relationships for T_{475}^{pl} as a median. The ordinate axis shows $\overline{V_s}$ (m/s), while the abscissa axis shows H in m. For a depth down to 200 m and $\overline{V_s}$ between 150-700 m/s, the plastic period can be increased up to 1.5 times in respect to the elastic period for a sand-gravel deposit, Fig. 11. Its increase is greater than twice in the case of clay-dust deposit. In

the case of a mixed deposit, Fig. 13, this increase is between 1.8-3.6 times. Knowledge of the period of vibration of the deposit prevents resonance between the structure and the deposit.

Seismic Zoning

Applying functional relationships for DAF(PGA)475, and T_{475}^{pl} , seismic zoning of UPS has been performed according to peak ground acceleration and the pastic period for a referent return period of 475 years (Figs. 14 and 16).

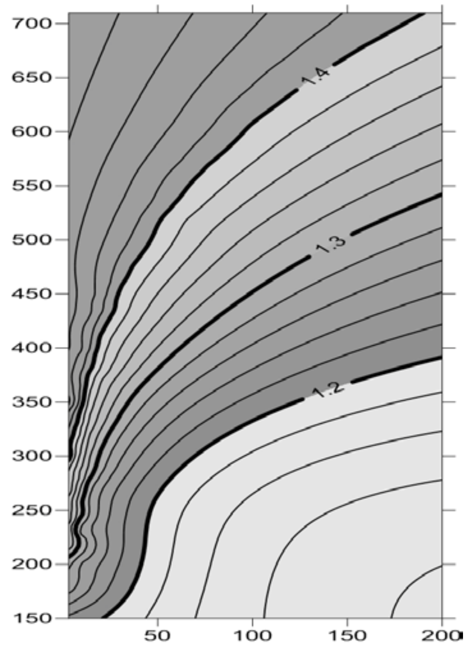


FIG. 11 DISTRIBUTION OF T_{475}^{pl} FOR SEND-GRAVEL

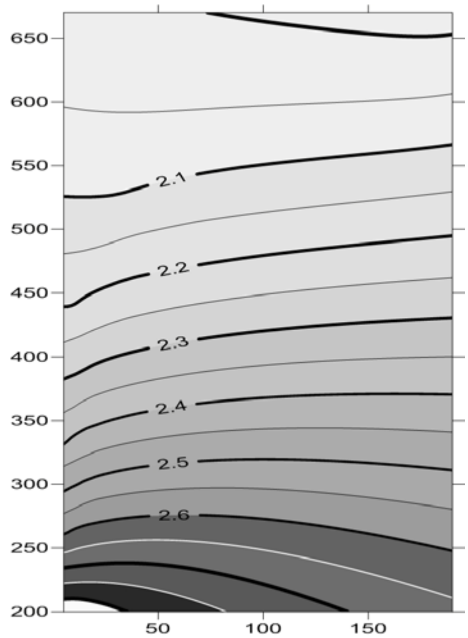


FIG. 12 DISTRIBUTION OF T_{475}^{pl} FOR CLAY-DUST

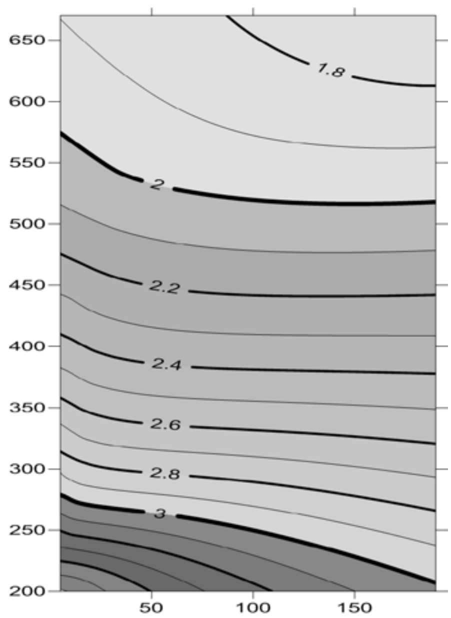


FIG. 13 DISTRIBUTION OF T_{475}^{pl} FOR MIXTURE

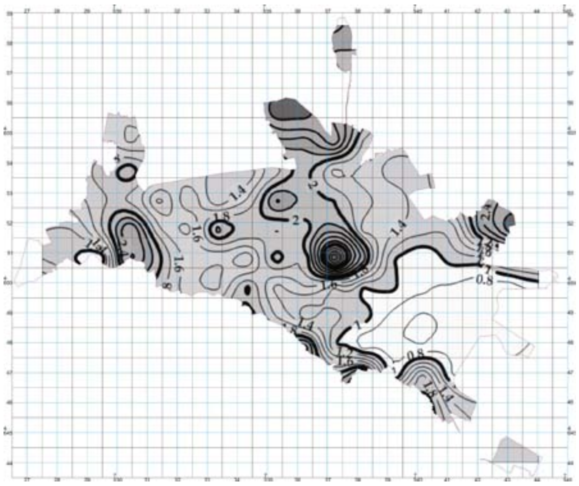


FIG. 14 DISTRIBUTION OF DAF(PGA)475 OF UPS

Fig. 14 shows that, in the UPS area with deep soil deposits, DAF(PGA)475 is less than 1.0. It has values between 1 and 2 in most of the city area and between 2 and 3 in a very small part. Its biggest value is around 3.6. This shows that the effect of the soil deposit upon the modification of acceleration at bedrock is important and that it must be taken into account in the seismic design parameters. By multiplying DAF(PGA)475 by acceleration of 0.211 g, the distribution of acceleration PGA at the free surface of UPS is obtained for a referent return period of 475 years. Defined in a way similar to that in the case of a return period of 475 years are, first of all, the empirical relationships for DAF(PGA), and then the distributions of DAF(PGA) and PGA at the free surface of UPS for all the remaining referent return periods.

To get an insight into the role and the importance of the fundamental period of vibration of the soil deposit of UPS, Fig. 15 graphically shows the distribution of its elastic period computed by application of the following formula:

$$T^{el} = \frac{4H}{\overline{V_S}};$$

where: H is the total thickness of the soil deposit, while $\overline{V_s}$ is the mean value of the shear velocity for its entire depth. Fig. 15 shows that, in the UPS area with very deep soil deposits reaching more than 200 m, it has a value between 0.6 and 1. In most part of UPS, its value is less than 0.4 seconds. The frequency modification that the soil deposit performs during the seismic effect changes the elastic period. This modification depends on both the soil deposit and the size of acceleration at bedrock and is shown by distribution of the plastic period given in Fig. 16.

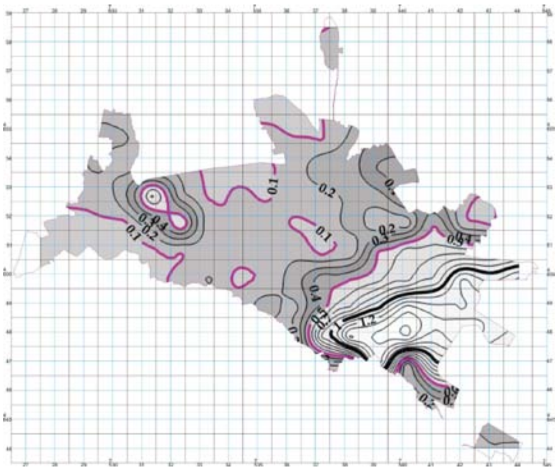


FIG. 15 DISTRIBUTION OF T^{el} OF UPS

FIG. 16 DISTRIBUTION OF T_{475}^{pl} OF UPS

The importance of this period is special for all the cases in which it has not been considered in the process of design of seismically resistant structures. If the designed fundamental periods of all the built structures in the UPS area are shown in the map given in Fig. 16, one can evaluate, in a very simple way, the seismic risk pertaining to failure of structures due to resonance. If this is done for all the referent return periods recommended by the design regulations, then it will be easy to assess the seismic risk for each design level. This would refer to the already built structures. As to the structures to be built in UPS in future, the distribution of the plastic period will mean managing of the seismic risk and its considerable reduction since the design engineer will know, in advance, the plastic periods of vibration of the soil deposits that should be avoided in the newly designed structure. Regarding the urban planning itself, the distribution of the plastic period will not only govern the definition of number of storeys of structures but will also enable managing of expenditures for the purpose of achieving greater seismic safety at a lower cost of the structure.

Recommendations for General Urban Planing

The results obtained from seismic microzoning represent a constituent part of the process of elaboration of the urban plan of Skopje city. These are used to direct the physical planning of the UPS led by the principle of consideration of microzoning as a preventive measure in the process of seismic protection of human lives and material goods, or planning the risk pertaining to expected earthquakes in advance.

The spatial distribution of PGA upon the free surface enables the following:

- Planning of the space through selection of corresponding locations for different types of structures depending on their importance in normal and emergency conditions;
- Proper selection of locations of structures in which technological processes are carried out and which represent a threat for the UPS from ecological aspects within a shorter or longer time period;
- Accurate planning of locations of structures of special importance in the case of a catastrophic earthquake, particularly those of vital importance for the UPS from the aspect of safety, accessibility and communication in the UPS and in the region;

- Recommendation of measures for reduction of PGA upon the free surface through selection of level of foundation and/or trough removal of the shallow soil deposit as a big amplifier of seismic effect at the bedrock;
- Planning of density of structures and population in areas with high values of PGA or in areas of the UPS with a high risk.

The distribution of the fundamental plastic period of vibration of the soil deposits enables knowing the dynamic characteristics of ground motion in advance and hence avoiding the state of resonance of the structures. For this, an important preventive measure is the recommendation for the application of engineering measures in the design of dynamic characteristics of structures based on the principle of providing greater seismic safety at a lower cost of construction.

Conclusions and Recommendations

From seismic aspect and based on the performed dynamic characteristics of the deposits in the urban area of Skopje city, for return period of 475 years it can be concluded that:

- Sand-gravel deposit is a favorable medium for earthquake effects since, in addition to amplification, it performs a considerable deamplification of acceleration and makes very slight changes in the elastic period of vibration of the deposit;
- Clay-dust in a deposit is unfavorable for seismic effects since it amplifies much more than it deamplifies. Due to the considerably changed characteristics of clay intercalations during the earthquake effect, the elastic period of vibration of the deposit increases up to 3 times;
- The sand-gravel-clay-dust mixture performs amplification greater than that of clay-dust, It performs less deamplification than sand-gravel and makes similar change of the elastic period of vibration to that of clay-dust.

The spatial distribution DAF(PGA) and T^{pl} in UPS enables application of scientific research in urban planning of the city based on its seismic zoning, taking care for the unfavorable effect of the deposits and, based on this, the seismic risk management of the Skopje city. It is recommended to investigate not only DAF(PGA) and T^{pl}, but also $DAF(T_i)$, for a greater number of periods of elastic spectrum of acceleration which will provide the possibility for empirical definition of the characteristic elastic spectra (Site Specific Spectra-SSS) of acceleration upon the deposit surface for a defined referent return period.

Also, it is recommended to develop empirical functional relationships for $DAF(T_i)$ and plastic period in which the third independent variable, i.e., the acceleration at bedrock, will be included. With this, SSS would be defined for any value of acceleration at bedrock.

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